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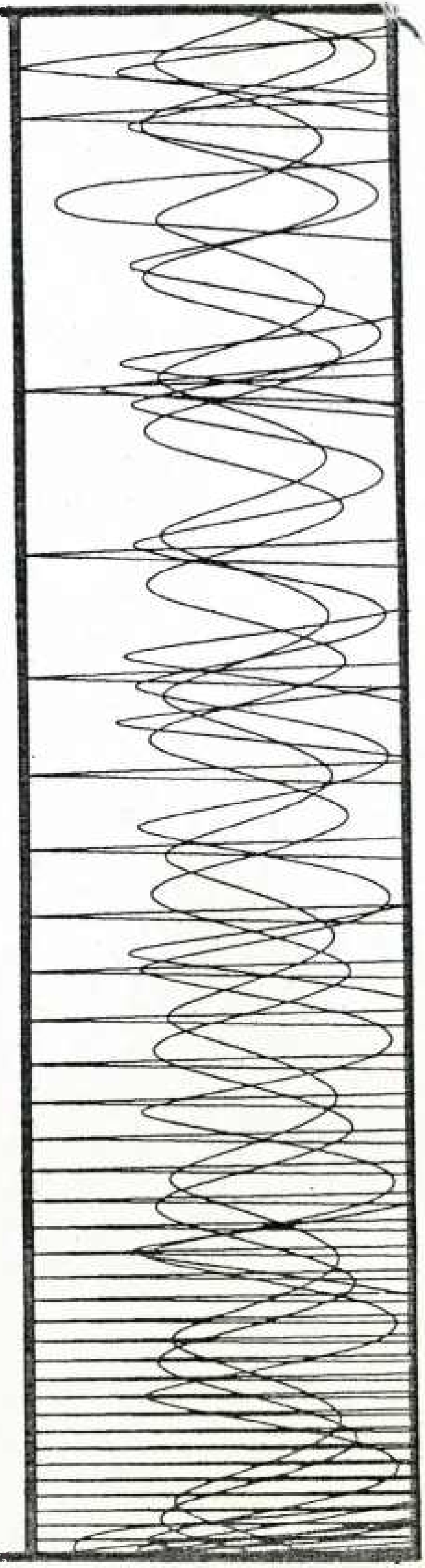

ENVIRONMENTAL SUPPORT
FOR
ELECTRO OPTICS SYSTEMS

FLEET NUMERICAL WEATHER CENTRAL

MONTEREY, CALIFORNIA

APRIL 1975

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by

KENNETH W. RUGGLES
CDR, USN

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ABSTRACT

Environmental effects on Electro-Optical systems are described, and the impact of these effects are crudely assessed. From this discussion, environmental support requirements are developed. The state of the science in responding to requirement is reviewed, and recommendations are made for a Navy research and environmental support program.

ENVIRONMENTAL SUPPORT FOR ELECTRO-OPTICS SYSTEMS

I. Introduction

The emergence of Electro-Optics (EO) systems as an important part of the military systems inventory has rekindled interest in the field of atmospheric optics. Effective design and use of communications systems, power transfer systems, and intelligence systems which exploit EO technology in the infrared and visible spectrum depend upon an understanding of atmospheric effects on light.

The goal of an environmental support system is to provide continuously updated assessments of EO weapons systems effectiveness in the natural environment. Assessments should provide information required to optimize weapons system employment tactics. Those steps needed for such assessments are shown in figure 1. Standard observations lead to environmental analysis and time-dependent forecasts. These in turn provide the data base for effects assessment models, which relate the natural environment to the weapons systems performance.

Environmental support of EO systems presents some new and unique problems. Atmospheric optics is not well understood by a large segment of the Navy environmental community. At the same time atmospheric forecast cause and effects relationships are not understood by those in the EO community. The consequence of this situation is:

A. The bulk of the basic atmospheric test-bed data related to modeling the atmosphere to EO systems effects are specialized aerophysical or micrometerological measurements. While these provide deeper insights into the physics of the problem, they are useless in establishing a foundation for environmental support unless they are simultaneously related to observable bulk atmospheric parameters (temperature, humidity, etc). From a Navy point of view, these observations are further deficient since few are representative of the ocean environment.

B. Present measurements and atmospheric modeling techniques appear deficient in describing atmospheric effects on EO systems.

C. Atmospheric research has not received adequate direction to provide relevant studies in the atmospheric optics area.

As a basis for discussing support of EO systems, a brief description of environmental effects is presented. These effects and the EO requirements are used to develop a baseline capability statement. From this point, actions are discussed and conclusions presented on steps leading to an acceptable support posture.

II. Environmental Effects

To catalog the effects of the environment on EO systems, consider a light source (either infrared or visible) radiating energy through the atmosphere toward some receiver (or target). The energy arriving at the receiver will differ from that radiated by the source due to the following effects:

A. Atmospheric Absorption (Clear-air absorption)

The gases which make up the atmosphere are selective absorbers. The amount of energy a given gas will absorb depends upon the frequency (wavelength) of the radiation and the molecular structure of the gas. The frequency dependence of the absorptivity of some of the more common atmospheric gases is shown in figure 2. For most systems the dominant clear air absorbers are atmospheric water vapor and carbon dioxide. While the percentage of carbon dioxide available in any atmospheric sample is relatively constant in space and time, the percentage of water vapor in a given sample will vary significantly in space and time. Normally EO systems are chosen to operate at wavelengths which are relatively immune to clear air absorption.

B. Atmospheric Turbidity

Particulate matter in the atmosphere scatters and absorbs light out of the beam path from the light source to the light receiver. The absorption effect depletes energy from the transmitted ray depending upon the composition of the particulates and the wavelength of the energy. The scattering effect reduces the energy arriving at the receiver in an amount determined by the concentration and size of the scatterers. For EO systems which must depend on contrast levels between the light source and the background light levels, such as imaging systems, particulate matter further degrade system performance by scattering ambient light into the receiver. This scattering decreases the receiver signal/noise ratios and in effect reduces light/background contrast levels.

To assess the effect of particulate scattering, it is usual to define a size parameter:

$$\alpha = \frac{2\pi r}{\lambda}$$

where: α = the non-dimensional size parameter

r = the radius of the scatterers

λ = the wavelength of the radiation

For values of α less than 0.1, Rayleigh Scattering Theory can be used. In this regime, for particles of a given size and index of refraction, scattering is inversely proportional to the fourth power of the wavelength. K(s), the scattering coefficient for unit length of path, is equal to:

$$K(s) = \frac{8}{3}\alpha^4 \left[\frac{m^2-1}{m^2+2}\right]^2$$

where m is the index of refraction of the scatterer. For Rayliegh scattering, the value of K(s) is usually quite small. For values of α greater than 100, the particle sizes are so large that geometric optics can be used to determine scattering effects. For most applications, however, the scattering processes in the atmosphere are caused by particles of size comparable to the wavelength of the radiation, say α = 1 to 50. Consideration of scattering in this regime requires use of the complete theory of scattering called "Mie scattering".

K(s) for Mie scattering is strongly dependent upon the size parameter. For water droplets, with an index of refraction of 1.33, K(s) approaches a value of 4 for α = 6, then oscillates between a value of 3 and a value of 1 with increasing α. The response curve acts as a damped sine wave, approaching a value of 2 for very large values of α, extending into the region of geometric optics. The importance of Mie scattering is best appreciated when one considers the range of droplet sizes associated with marine fogs. Droplet size distributions of drops ranging from 2 to 50 microns are common for various marine fogs. Consider these drop sizes with radiation in the 4 micron window. Small variations in the type and size distribution of the fog particles will effect critically the performance of an EO system operating in this range.

C. Atmospheric Refraction

Atmospheric refraction is the result of Snell's Law bending of light rays as they pass through a medium of changing index of refraction. (N-gradient). For optical wavelengths, the effect is referred to as astronomical refraction. The physics of the phenomena is identical to that of the familiar radar refraction problem, except optical refraction is a function of temperature gradient only, in contrast to the strong humidity dependence of radar refraction. The refractive index gradient function for optical wavelengths is given by the formula [2].

$$\frac{dN}{dh} = \frac{79}{T}\frac{dp}{dh} - \frac{79P}{T}\frac{dT}{dh}$$

where: h = height (km)

N = N units of refractive index where $N=(m-1)10^6$

T = temperature (°C)

p = pressure (mb)

Because of the complete similarity of radar refraction and optical refraction, the ray-trace models used in radar refraction are usable for optical refraction except the input is driven by a different refractive index function.

For laser applications, accurate pointing of the light energy at a target is extremely important. Short term variations in the value of N of space scales equivalent to the light path and of time scales of tens of seconds or longer causes the light beam to move around its intended target. This variability of the ray-path with time is called "beam-wander". For the purpose of modeling, beam wander can be considered a large-scale turbulence effect, explicitly described by ray-trace methodology.

D. Turbulence. For EO systems, beam wander phenomena defines the "large scale" of turbulence. However, atmospheric turbulence exists at all scales. An effect of particular importance is the "small scale" turbulent effects, normally of time scales of a second or less and space scales of a meter or less. Turbulence at this scale causes the scintillation of light, and dancing or distortion of images.

For scintillation, the dominant turbulence scale size is that equal to the Fresnel-zone size $\sqrt{\lambda L}$, where L is the path length between the source and the observer, or, for for space-earth paths, the distance between the observer and the turbulent atmospheric layer. Predominant scale sizes range from 1 cm to 10 cm for typical optical paths.

Since atmospheric turbulence is described statistically, the intensity of the variability of N-gradient is described by an atmospheric refractive index structure function, C_N^2 . This function is units of meters $^{-2/3}$. Its value ranges over 4 orders of magnitude, varying from 10^{-17} to 10^{-13} as the level of atmospheric turbulence increases. C_N^2 is a highly idealized turbulence structure constant, conceptually similar to and relatable to the temperature structure function C_T.

The entire use concept of a structure function assumes that the turbulence of interest to EO Systems exists at wave numbers lying within the "inertial subrange" of a Kolmogorov spectrum. In the Kolmogorov theory of the spectral dependence of atmospheric turbulence, turbulent energy is assumed to be input into the atmosphere at relatively long wave lengths, and is dissipated at very short wave lengths. In order that turbulent energy may be transferred from the long wave lengths of generation to the short wave length of dissipation, there must be an energy cascading process, in which large eddies break up into and transfer their energy to smaller eddies. Turbulent eddies which lie in the spectral range between turbulence generation and turbulence dissipation are said to lie within the inertial subrange, and the energy at any wave number $\Phi(K)$ therefore is completely described as a function of wave number by an expression of the form.

$$\Phi(K_x) = C_x K^{-5/3}$$

where C_x is the turbulent structure function, and x can be either T for temperature or u for velocity. To the extent the structure of the atmospheric turbulence at scales of interest to EO applications follow the Kolmogorov theory, one can relate the value of C_x to observable bulk parameters in the atmosphere, such as hydrostatic stability, wind shear, and scale height.

E. Atmospheric Cooling. If the beam of light passing through the atmosphere is sufficiently strong, and if the wave lengths of the radiation is such that the atmosphere is a strong enough absorber, the optical energy will heat the atmosphere. In the absence of any wind to advect away the heated air, the change in refractive index of the locally-heated air results in beam defocusing, commonly called "Thermal blooming". Therefore, for high energy applications, the cross-wind component across the beam becomes important, since the cross wind will advect away heated air and reduce thermal blooming effects.

F. Ambient Conditions

The term "ambient conditions" is used herein to lump together environmental effects not directly associated with the atmosphere, but which, none-the-less, must be considered in any forecast of systems effectiveness. Ambient conditions are of primary importance in passive EO systems, and of less importance in active (radiating) EO systems. Table 1, adapted from Huschke [3], lists important ambient conditions for 2 passive EO systems.

Targets, backgrounds, and countermeasures represents the target as an enemy presents it. Each of these may be effected by some degree by weather effects. For example, the rate of solar insolation may improve or degrade FLIR target-to-background contrast ratios due to differential heating of the two surfaces. Optical and thermal clutter of the background, such as encountered by breaking up sea-ice, may completely mask the target signals.

TABLE 1

AMBIENT FACTORS AFFECTING ELECTRO-OPTICAL SENSOR PERFORMANCE

Factor	Low-Light-Level Television (LLLTV)	Forward-looking Infrared (FLIR)
Target	Reflectance and projected area of each exposed surface component. (Reflectance changes with surface condition--dusty, rusty, wet, etc.) Target velocity	Temperature, emissivity, and projected area of each exposed surface component. (Emissivity changes with surface condition) Target velocity
Background	Optical "clutter"--Reflectance distribution of background elements (trees, bushes, grass patches, etc.)	Thermal "clutter"--temperature and emissivity distribution of background elements. (Water puddles, treetops, patches of bare dirt all sometimes appear hot)
Environment	Ambient Illumination (directional or diffused)	Weather and weather history (hours of sunshine previous day, hours since precipitation, wind velocity, percent overcast, time of day, of year, temperature, etc.)
Countermeasures	Ease of shielding or decoying	Ease of shielding or decoying

III. Importance of Environmental Effects on EO systems.

How important is each of the environmental effects on present EO systems? If the operating environment has little effect on an EO system, or if an environmental effect has a significant impact on an EO system but the effect is invariant in space and time, environmental support systems can have little impact on systems effectiveness. As a crude method of weighing the importance of each environmental effect, we will adopt a scale running from 1 to 4; where:

1 - The environmental effect is of little or no importance in improving systems performance. This implies either there is no effect, or that any significant effect can probably be overcome by proper engineering.

2 - Forecasting the environmental effect is important in improving system performance. This implies a condition such as moderate environmental sensitivity with moderate environmental variability.

3 - Forecasting the environmental effect is highly important to proper systems employment. Here, either the environmental variability or the system sensitivity is extreme, but the other parameter has, at worst, a moderate effect.

4 - Forecasting the environmental effect is essential to proper systems employment. In this category, both system sensitivity and parameter variability are extreme. Category 4 states there are frequent cases where the system will not perform due to the environmental degradation.

Table II is an environmental effects matrix summarizing the effect of the parameters previously discussed on 4 candidate weapons systems.

TABLE II

WEAPONS EFFECTS

Environmental Effect	Low-Light Level TV	Fwd Look IR	EO System LASER COMMS	LASER WEAPONS	TOTAL
Absorption	1	1	1	1	4
Turbidity	4	4	3	4	15
Refraction	1	1	2	2	6
Turbulence	2	2	1	4	9
Wind	1	1	1	2	5
Ambient Cond.	3	3	1	1	8
TOTALS	12	12	9	14	

Low-light level TV (LLLTV) and forward-looking infrared (FLIR) systems are complementary passive guidance systems for "smart bombs". While both are equally effected by the environment, their effects are different for a given environmental condition. Therefore, environmental forecasts become crucial in proper strike mission planning, target selection, and aircraft bomb loading. Ambient conditions and atmospheric turbidity are major planning factors in such operations. Both the LLLTV and FLIR systems are presented as representatives of the typical passive EO systems.

Laser communications and weapons systems are characteristic of the active laser systems. The major difference between the two is the allowable signal attenuation along the path. For laser communications, concern arises when the environmental affects result in signal attenuation in excess of the communications link margins, or when the energy propagation is anomolously long, resulting in opportunity for adversary signal intercept. For laser weapons, on the other hand, the goal is to deliver as much power as possible to a given spot. Accordingly, much less signal attenuation can be tolerated. Laser weapons encounter the same problems as laser communications, but are much more sensitive to these effects. Applications scenarios differ markedly for communications from and laser systems, since the laser weapons systems are employed over short ranges, while the communications systems are designed for longer paths.

If we order the environmental variables in order of importance (Table III), atmospheric turbidity is by far the most crucial problem, while turbulence and ambient conditions are about equally important for general systems. Refraction, wind, and clear air absorption are relatively unimportant, except for specific systems.

TABLE III

Environmental Variables in Order of Importance

Variable	Weight
1. Turbidity	15
2. Turbulence	9
3. Ambient Condition	8
4. Refraction	6
5. Wind	5
6. Clear Air Absorption	4

Implied in the Table III ordering is an ability to engineer out a significant part of any physical effects due to refraction. Engineering literature suggests laser tracking systems are most likely the best solution to astronomical refraction and beam wander phenomena. If suitable engineering solutions are not achieved, the relative importance of refraction effects should be reevaluated.

IV. Ability to Forecast Environmental Effects

a. General Problem

The issue of scale becomes the dominant issue in providing environmental support to EO systems. All of the important environmental effects are described in the microscale, i.e. by phenomena smaller than that scale usually implied by conventional bulk measurements in the atmosphere. The microscale normally includes phenomena of linear dimensions of the order of meters or less. At the same time, environmental measurements are interpreted and forecast on a macroscale, which we define after Smagorinsky [4] as the smallest scale for which we explicitly solve the equations of motion. The macroscale is usually defined by space scales on the order of hundreds of kilometers. Typical explicit operational models presently computed by the Naval Weather Service are computed on a grid mesh of approximately 400 kilometers. The specification of microscale processes from macroscale computations requires the use of parameterization. Implicit parameterization describes how the smaller scales react to and interact with the larger scales.

The typical strategy for solution of scale interaction problems is to construct a hierarchy of models which evolve from the macroscale to the microscale through systematic parametization of successively smaller scale sizes, as shown in figure 3. The mesoscale is that scale between the macroscale and the microscale. Figure 3 shows dotted lines labeled "feedback loop" running from the smaller scale model to the larger scale model. In order for model characteristics to evolve in a more nearly realistic fashion, the physics of the models should be allowed to interact into self-determining states fully considering scale interactions. In order to do this, however, the models must be simultaneously computed together, in a "nested" or parallel fashion, which raises the issue of trade offs between computer power verses skill and speed.

The coin of the realm in environmental forecasting is raw computer power, usually described in millions of instructions per second (MIPS) throughput. In this coin, the quality and quantity of service one receives depends upon how much one can afford. At this time, the quality of specifications through the macroscale is limited by the cost. To put this cost in perspective, one strategy to improve the solution for weather events is to increase the resolution of the explicit models (i.e. make the macroscale smaller). To increase the resolution of the three space dimensions by a factor of 10, the cost increase in computational power is 10^4. Typically, environmental forecast models in an operation environment must run at least 70-100 times as fast as real time to be useful. (i.e.; a three day forecast is produced in about 1 hour or less). Modest explicit models on a 400 km grid with macroscale parameterization without feedback cost approximately 2 MIPS. Reasonable operational explicit models with a nominal 200 km grid and full mesoscale nesting costs about 40 MIPS. In terms of dollar costs, a 40 MIP machine is in the vicinity of 20 million dollars. In view of the costs involved in computation, planners of research programs must design forecast techniques with a clear eye on the economics of the computational problem. Elaborate and explicit nested models rapidly exceed the economic and technical feasability of computers projected over the next decade.

Returning to specifics of the EO problem, a general assessment of present ability to specify microscale processess is either marginal or non-existent. The macroscale problem is reasonably well defined and more or less adequately supported by national research. Parameterization into the mesocale has been demonstrated to the level of skill required for further work in the microscale, but requires expansion of computer resources and advanced development to transition exploratory work into operational capability. The microscale processess are discussed separately.

b. Turbidity

Atmospheric opacity due to turbidity is the single most important factor in EO systems performance, and at the same time the least understood. Limited experimentation and sampling has provided some insights into relationships which might exist between large scale thermodynamic processess and aerosol/hydrometeor distributions. As of this time, however, the insight into the physics of clouds and aerosols is not adequate to allow for the explicit generalized specification of particulate matter size and number density in the atmosphere. At best, we can strive for some implicit solutions during the coming decade.

For discussion, we break aerosols and hydrometeors each into two subclasses.

Aerosols (suspended particles of size 3μ or less)

Continental Aerosols, to include all dusts, man-made effluents and other aerosals from all terrestrial and extraterrestrial non-uniform sources.

Marine Aerosols. Those aerosols which are primarily of oceanic origin, such as salt nucleii.

Hydrometeors. (water droplets 3μ and larger)

Fogs. To include all impairments by hydrometeors to horizontal ground visibility for EO systems.

Clouds, to include all impairments to EO visibility in the atmosphere not extending to the ground.

In order to reduce the aerosol problem to a tractable scope, it is suggested that heavy-handed narrowing of the problem will be necessary. Suspended dusts from volcanic eruptions or dust storms (such as often occur over the Eastern Atlantic off the African Coast) produce spectacular results, but in the framework of day-to-day operations are rare events, and can be ignored. Other aerosols which complete the continental aerosol set can be important, since they are commonly advected over the sea. While these aerosols may be important, their consideration in forecasting at this time must be either neglected or only grossly treated. Adequate distribution models do not exist, and research to gain insights into continental aerosols is, at most, in a rudimentary exploratory stage of learning about "Typical" aerosol distributions. It is doubtful if this activity will advance much in the next decade. Byers [5] summed up the problem by stating,

> "In a census of particles of the atmosphere, it is desirable to determine the size, number concentration, chemical composition, charge carried, if any, radioactivity, if any, at all points in the atmosphere. This is a task which may never be accomplished in the twentieth century."

Localized distribution of some specific aerosols over extremely limited geographic regions can be predicted from time dependent bulk weather parameters. There are a variety of diffusion models which specify the distribution of man-made aerosols in and around urban areas developed in response to urban pollution requirements [6]. These models may be applicable for EO effects prediction in areas where urban haze is important over limited geographic regions.

The distribution of marine aerosols over the open ocean may be a more tractable problem. The near-surface distribution of aerosols in general has been observed to be a function of relative humidity, wind speed, sea state and precipitation history. (Both water vapor and aerosols come from the same source, the ocean, and usually both are depleted by similar mechanisms such as rainout.) Marine aerosols, because of their hygroscopic nature, are part of a size continuum of particles extending from nucleii into cloud droplets, all with nearly the same index of refraction. In terms of global oceanic prediction, there is some hope for implicit solutions to the measurement of size and number distribution of particles in fogs, clouds, and aerosols.

Figure 4 presents steps required for solution of the atmospheric problem of marine aerosol distribution. (Many of these steps are appropriate to other problems as well.) Atmospheric observations and forecast models cover a global domain, and are computed at a grid mesh presently at 400 km. The macroscale forecast problem is a computer-limited problem, since boundary conditions and atmospheric influence functions limit the minimum extent of a forecast domain to a hemisphere.

The fundamental outputs of the forecast models are mass and water vapor distribution in the atmosphere, the atmospheric three dimensional motion field, the sea state, and the amount of precipitable water at each grid point.

Given the macroscale forecast and in some cases (clouds) meso-scale observations, mesoscale bulk parameters important to aerosol and turbulence distributions can be forecast. Because of the interaction of the models describing the various scales, they should be computed together in a parallel or "nested" mode. Present operational boundary layer models and cloud distributions models have been grossly simplified so they can be accomodated in existing operational computers.

The problem becomes science-limited in the area of microscale specification. Models do exist which can specify the monodisperse distribution of particles based on bulk atmospheric specification, but these models have not been well verified. Much more work is required in stochastic dynamic modeling to create realistic droplet distribution in the atmosphere. Explicit solutions of atmospheric droplet distributions are some time in the future. While work in this area should be undertaken, a parallel effort is required to collect at-sea observational evidence designed to provide implicit parameterizations of droplet distributions as a function of bulk specifications in the marine atmosphere, including cloud distributions. Cloud distribution studies are greatly facilitated by present high resolution satellite imagery data capabilities.

c. Atmospheric Turbulence

Specification of atmospheric turbulence in the marine environment is a problem an order of magnitude simpler than the turbidity problem, primarily because it can be studied within a reasonable complete theoretical framework. Questions are raised about the structure of atmospheric turbulence at sea which arise from the dynamic nature of the oceanic boundary layer. Present theory assumes a rigid boundary.

The overall forecast problem for turbulence is identical in the macro and mesoscale as described in figure 4 in the turbidity section. (Figure 5 outlines the problem, beginning at mesoscale specification.) The major difference is in the detail and accuracy of mesoscale specification and the verification of C_N^2 models. The feasibility of specifying global distributions of C_N^2 within the framework of existing large-scale forecast models has been demonstrated by McConathy [7]. The primary requirement in the turbulence area is an observational program to establish the level of confidence and range of validity of existing theory in a regime influenced by a dynamic boundary, and where possible to establish the basis for extensions to existing theory. Lawrence, Ochs, and Clifford [8] have shown that there are a number of cases where simple turbulence parameterization breaks down in specifying $C_N{}^2$. Observational programs such as those of Davidson [9] and Ochs and Lawrence [10] indicate that separate models probably shall be required for the constant stress layer (extending from the ocean surface to some tens of meters into the atmosphere) and for the Ekman Layer (extending from the constant stress layer to several km). The importance of the location and strength of the inversion, as shown by Frisch and Ochs [11] will require inversion parameterization in operational atmospheric boundary layer models in the same sense the thermocline is parameterized in oceanographic models.

The turbulence specification program has progressed to the point where a coupled quasi-operational, theoretical modeling effort of some magnitude can be undertaken, supported by and supporting an observational verification program.

d. Ambient Conditions

Ambient conditions in the marine environment can be rather precisely established due to the general uniformity of the environment. Unfortunately the application areas for weapons systems which are strongly effected by ambient conditions are the hard terrain areas. Weapons effectiveness models exist which consider ambient conditions in terms of target/background contract ratios (signal to noise (S/N) ratios), sun angle, and the depression (elevation) angle of the line of sight. Unfortunately the scale of variability for most ambient conditions is so small that the prospects of establishing a unified global data base is remote. The basis for ambient conditions estimates will have to remain in-site measurement or the objective interpretation of intelligence photography in planned target areas. High-resolution multispectral satellite imagery data streams may provide ambient conditions estimates, and should be investigated as possible data sources.

The modeling approaches to solution of ambient condition effects has been studied by Huschke, [12]. Figure 6 presents the functional relationships for infrared detection probability, as extracted from Huschke's discussion. Note in figure 6 the strong dependence of the noise equivalent temperature difference on forecastable mesoscale ambient conditions.

e. <u>Other Parameters</u>

Refraction, cooling, and clear air absorption are all clearly second order effects and all are, to some degree, deriveable from existing forecast fields. In terms of EO systems effects research, the reduction of uncertainty in estimating weapons systems effectiveness attributable to these effects does not warrant any significant effort toward improving existing capabilities at this time.

V. Climatology

As the basis for engineering design studies and for dynamic model stabilization, adequate climatologies of specific parameters are required. Unfortunately, most of the historical measurements which have been taken do not relate to specific EO requirements. This requires other approaches to the climatology issue.

An approach which has been used extremely effectively is to create a special parameter climatology by processing the existing macro-scale climatologies through parameterization programs. In many cases, it turns out this approach is the only approach to an adequate climatology. This approach was used to create present ocean wave climatologies and acoustic transmission climatologies. The disadvantages to this approach are:

(a) The climatology is only as good as the model that was used to produce it. The climatology may require reprocessing when better models are available.

(b) The building of such a climatology is costly and time-consuming.

The Naval Weather Service Command Fleet Numerical Weather Central in Monterey maintains an extensive worldwide macroscale climatology and observational data base in fully digital form. The basic contents are shown in table IV.

TABLE IV

FLENUMWEACEN DATA BASE

Historical Atmospheric Fields	288,000
Historical Oceanographic Fields	112,000
FNWC Atmospheric Fields	671,000
FNWC Oceanographic Fields	385,000
Ship Synoptic Observations	43,000,000
Naval Air Station Hourly Obs	3,750,000
Bathythermograph Observations	
(a) Digitized XBT traces	214,000
(b) Mechanical Bathy	105,000
(c) Station Casts	620,000
	939,000

The historical fields shown in table IV are 2-dimensional macroscale arrays of northern hemisphere environmental parameters extending for continuous period since 1946. For some parameters (surface pressure and implied winds) records are digitally available for an almost continuous period back to 1899, but are not physically held at FLENUMWECEN. The Naval Weather Service Climatology support service maintains active liaison with both national and international activities, and can acquire and process additional climatologies.

Some climatologies which are relevant to EO systems are:

a. cloud climatologies. A number of digitally and manually prepared cloud climatologies exist. The digital climatologies are primarily satellite cloud brightness climatologies and cloud temperature climatologies. These data extend back to the early 1960's and are achieved in various resolutions extending from 2 n. mi on up. These climatologies are primarily retained by NOAA and NASA. A three dimensional modeled cloud climatology exists on a nominal 50 n. mi grid mesh created from the USAF 3-dimensional nephanalyis program.

b. Fog climatologies exist, but are very crude. It is doubtful if they are of any value. The parameter is the percentage occurence of fog in any location by time period.

c. Aerosol and haze climatologies do not exist. Such climatologies will probably have to be created by modeling and model development.

d. C_N^2 Climatologies. A first-cut C_N^2 climatology can be created now with existing knowledge of the marine boundary layer. The climatology would be understandably crude, but as models improve so would the climatology.

e. Background Climatologies are discussed in section IV.

VI. Effects Models

Given explicit specification of the microstructure of the atmosphere, there are a superb set of effects models describing the result of atmospheric effects on EO systems. For passive imaging EO systems, the Air Force and Rand Corporation have developed very good models providing quantitative assessments of environmental effects on airborne EO systems in a tactical environment. For active laser systems, the Navy Research Laboratory has excellent effects models which appear suitable for adaptation to tactical effects forecasting when active system scenarios are better established.

While these models have been employed to assess EO designs and feasibility, there is a need to employ them in a variety of atmospheric scenarios to better define the bounds of atmospheric uncertainty which can be tolerated by the various EO systems. This provides the basis for better understanding of the forecast problem.

VII. Conclusions and Recommendations

a. Support and training. Atmospheric optics is part of the broader area of physical and boundary layer meteorology. In the last two decades, the stress in the meteorology science has been directed toward dynamic and synoptic meteorology, resulting in very few trained and qualified physical and boundary layer meteorologists. Presently the Navy does not have adequate physical meteorologists to support any sustained level of EO support. The following personnel and management actions are proposed to establish an adequate personnel training and support posture:

(1) Establish military 181X billets in CHNAVMAT, NRL, and NELC for the purpose of providing management consultation and scientific expertise to the EO community, and provide a position for training the Navy environmental community.

(2) Establish an environmental effects modeling group consisting of civilian and military scientists dedicated to transitioning 6.1 environmental and effects modeling efforts into operational effectiveness models. The group would concern itself with designing models around existing environmental support systems and designing output packages appropriate to the actual tactical scenarios and tactical support requirements.

b. Operational Requirements. Operational requirement (OR) documents are required to provide the basis for a properly structured environmental support program. Appendix A is provided as a proposed draft for an OR.

c. Aerosol and hydrometeor research. There is an urgent need for an organized research program to specify marine aerosols and hydrometeors. The research program will require three basic, parallel, and coordinated 6.1 efforts:

(1) A model development effort to parameterize droplet size and number distribution based on mesoscale measurements or analyses of bulk parameters. A navy group and/or a university competent in cloud physics and fog modeling is proposed as an appropriate site for this work.

(2) A measurement program at sea, in which bulk parameters and hydrometeor droplet size and number distributions are measured. Such a measurement program should be accomplished, to the extent possible, from an at sea shipboard platform, such as an MSTS ship, which spends a significant part of its time in the open ocean.

(3) A measurement program at sea to relate bulk parameters to laser effects. Because of the high technological risk of effectively parameterizing droplet size and number distributions, a "brute force" correlative engineering solution may be required to provide adequate answers in a reasonable time frame. This effort, to be most efficient, should be performed simultaneously with effort (2), above, to provide the basis for model validation.

d. Turbulence research. The turbulence research presently being performed for Navy EO weapons systems is well under way to validate atmospheric theory.

(1) The turbulence program has progressed to the point where effort should be directed at assessing the adequacy of present boundary layer models to parameterize C_N^2 in the constant stress layer. Concurrent observational and modeling programs are required in this area.

(2) A program should be initiated to properly model the strength and location of the boundary layer atmospheric inversion. This

work should be done within the framework of existing operational macroscale models, with an objective toward EO effects definition in the Ekman Layer.

e. Instrumentation development. An assessment of instrumental requirements will require further research into the adequacy of existing models to support EO technology. The only area of instrument development which is now apparent as one requiring renewed emphasis is an instrument to measure the atmospheric vertical structure in the first 7-10 km of the atmosphere. Presently such atmospheric sounding is performed using balloon borne radiosondes. This device measures temperature and humidity as it is carried aloft by a helium-filled balloon, and transmits its observations back to the ground. For EO applications, present operational radiosondes suffer in two areas:

(1) The radiosonde vertical resolution is inadequate to measure the small-scale vertical variability of temperature.

(2) The radiosonde system complexity requires a skilled team to launch and interpret results. This limits the use of the radiosonde to over land and to use in a few selected ships staffed with skilled personnel.

An instrument is required which can be operated by personnel with limited training, and which will sense the vertical temperature, humidity (and wind) structure in the first 7-10 km of the atmosphere. The instrument should be sized and priced so it can be placed on a variety of Naval and cooperating merchant vessels. At-sea deployment of adequate numbers of these devices will allow proper specification and modeling of the inversion layers important to EO applications.

In addition to in-situ devices such as radiosondes, there are a number of remote probing devices being proposed. Acoustic sounders [13] are being developed, and infrared spectrometers have been proposed.

f. Priorities. The following priorities are proposed for implementing the actions recommended herein.

(1) Support and Training management

(2) Preparation of OR documentation

(3) Aerosol and hydrometeor research

(4) Instrumentation development

(5) Turbulence research

Priorities have been set on the basis of identifying those areas which most urgently need some attention to provide a balanced program. The priorities do not imply existing development should be curtailed in preference to other work, since the health of existing programs, such as turbulence research, has placed it rather low on the priority list.

REFERENCES

1. Nawrocki, Paul J. and Robert Papa, 1963, Atmospheric Processes, Prentice-Hall, Inc.

2. Lawrence, Robert S. and John W. Strohbehn, 1970, A Survey of Clear-Air Propagation Effects Relevant to Optical Communcations; Proc IEEE, Vol 58, No. 10, October 1970.

3. Huschke, R. E. and R. R. Rapp, 1970, Weather Service contribution to STRICOM Operations - A survey, a Model, and Results. Rand, Inc report R-542-RR, September 1970.

4. Smagorinsky, Joseph, 1974, Global Atmospheric Modeling and the Numerical Simulation of Climate, in Weather and Climate Modification edited by W. N. Hess, John Wiley and Sons.

5. Byers, Horace Roberts, 1965, Elements of Cloud Physics, University of Chicago Press.

6. Stern, Arthur C., 1970, Proceedings of Symposium on Multiple-Source Urban Diffusion Models, U. S. Environmental Protection Agency Air Polution Control Office, Research Triangle Park North Carolina.

7. McConathy, Donald R., 1972, Specification of Marine Surface Boundary Layer Parameters, Naval Postgraduate School, Monterey, California.

8. Lawrence, R. S., G. R. Ochs, and S. F. Clifford; 1970, Measurements of Atmospheric Turbulence Relevant to Optical Propagation, J. Optical Soc Am, Vol 60, No. 6, 826-830 June 1970.

9. Davidson, K. L. 1973, Describing Meteorological Conditions for Optical Propagation; Minutes of the Meteorological Group, 35th Meeting of the Range Commanders Council, Space and Missile Test Center, Vandenberg AFB, California.

10. Ochs, G. R.; and R. S. Lawerence, 1972, Temperature and C_N^2 Profiles Measured Over Land and Ocean to 3 km Above the Surface. NOAA Technical Report ERL 251-WPL22.

11. Frisch, A. S. and G. R. Ochs, 1975, A Note on the Behavior of the Temperature Structure Parameter in a Convective Layer Capped by a Marine Inversion, NOAA/ERL/Wave Propagation Laboratory draft manuscript.

12. Huschhe, R. E., 1975, Predicting Visual and Infrared System Performance as a Function of Environmental Variables: A Technique Briefing. Rand Corp Working Note WN-8932-PR/RC.

13. Little, G. Gordon, 1969, Acoustic Methods for the Remote Probing of the Atmosphere, Proc of IEEE, Vol 57 No. 4, 571-578, April 1969.

ADDITIONAL REFERENCES

Caledonia, G. E., P. Nebolsine, J. D. Teare, and K. L. Wray, 1974, Aerosol Propagation Effects, Physical Sciences Inc., Wakefield Mass. report PSI TR-13, ARPA order 2439.

Dowling, James A., and Peter M. Livingston, 1973, Behavior of Focused Beams in Atmospheric Turbulence: Measurements and Comments on the Theory, J. Optical Soc of America, Vol 63 No. 7, July 1973.

Hayes, J. N., P. B. Ulrich, and A. H. Aitken, 1973, Effects of the Atmosphere on Propagation of 10.6 μ Laser Beams, Applied Optics, Vol 11, Feb 1972.

Hogge, Charles B, 1974, Propagation of High Energy Laser Beams in the Atmosphere, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, report AFWL-T ~~1~~74-74.

Lin, C. C., 1961, Statistical Theories of Turbulence, Princeton Aeronautical Paperbacks, Princeton University Press.

Lumley, John L., and Hans A Panofsky, 1964, The Structure of Atmospheric Turbulence, John Wiley and Son, New York.

Lutomirski, R. F., R. E. Huschke, W. C. Meecham, and H. T. Yura, 1973, Degradation of Laser Systems by Atmospheric Turbulence, Rand Inc. report R-1171-ARPA/RC, ARPA order 189-1.

Plate, Erich J., 1971, Aerodynamic Characteristics of Atmospheric Boundary Layers, U.S. Atomic Energy Commission.

APPENDIX A

DRAFT OF OPERATIONAL REQUIREMENT

I. OPERATIONAL NEED

a. Threat. The variability of the natural environment strongly effects the performance of Electro Optical (EO) weapons systems, imaging systems, and communications systems.

b. Operational Problem. Failure to anticipate and counteract the effects of the environment on EO weapons systems will result in weapons systems being seriously degraded, and under some conditions will result in exposing friendly forces to unwarranted risk and excessive casualty. For example, launching aircraft on a strike mission with low-light television guidance bombs when Forward-looking infrared guidance bombs would perform more effectively for a particular target environment exposes the strike aircraft to the hazards of hostile opposition with reduced target damage. Presently the tactical commander is unable to anticipate the effects of the environment to any degree of certainty to optimize his weapons employment.

II. OPERATIONAL CONCEPT

Proper environmental threat anticipation can result in threat avoidance, or the instigation of precautionary measures (such as tactics) to reduce the exposure caused by degraded systems performance or exploit the advantage gained by differentially improved systems effectiveness.

A basic environmental forecast service is maintained by the Navy to provide environmental threat anticipation for other weapons systems.

The capabililities of this system should be extended to provide Navy-wide environmental effects assessment service for EO systems. The weather assessment system should provide measures of EO systems effectiveness as a function of space and time in the natural environment. Measures of systems effectiveness will be periodically transmitted to fleet units depending on EO systems support by routine Navy communications.

Environmental threat anticipation for EO systems requires a fully supported environmental system. Elements of the system include conventional and remote satellite sensing of the physical environment, objective numerical prediction of the time and space evolutions in the environment, and objective numerical anlysis of the weapons system response to the environment, resulting in weapons systems effectiveness measures. Much of this system already exists in the Navy Weather Service, but must be augmented primarily in computational resource, to handle the additional tasking. The systems development should analyize the support task and recommend specific measures to restructure the environmental support system to respond to requirement.

Training support requirements include improved scientific training of Navy environmentalists in physical and boundary layer meteorology and training of the operational Navy community in tactical options to environmental effects.

III. CAPABILITIES REQUIRED

a. Performance Goals

(1) Forecast for a period of 5 days in the future to an accuracy of not worse than 60% accuracy at the end of the period the following environmental parameters:

(a) Atmospheric turbidity. To include the number density and particle size distribution of oceanic aerosols, hazes and fogs, and a crude estimate of continental dusts and aerosols along a horizontal or slant range path extending to the lowest cloud layer.

(b) Cloud type and distribution, to include the particle size and distribution, cloud bases, cloud tops, and centimeters of precipitable water.

(c) Vertical temperature gradient from the surface to 5000 ft., to include definition of the height and strength of low-layer inversions for purposes of refractive index determination.

(d) refractive index structure function C_N^2 for the surface layer of the atmosphere extending to an altitude of 5000 ft.

(2) Prepare and maintain quantified historical files cataloging

(a) Historical global cloud distributions

(b) Surface reflectivities and emissivities in potential applications areas

(3) Using the above environmental fields, employ numerical effects models to assess the usefulness and optimum tactical employment of EO weapons systems. Parameters should include (depending on EO system).

(a) Signal attenuation due to absorption and scattering by atmospheric aerosols and clouds.

(b) Signal redirection due to refractivity and beam wander.

(c) Target-to-background contrast ratio.

(d) For passive systems, ambient illumination.

(e) Scintillation due to atmospheric turbulence.

(4) Provide environmental effects measurements to tactical forces to be updated as frequently as once every 12 hours.

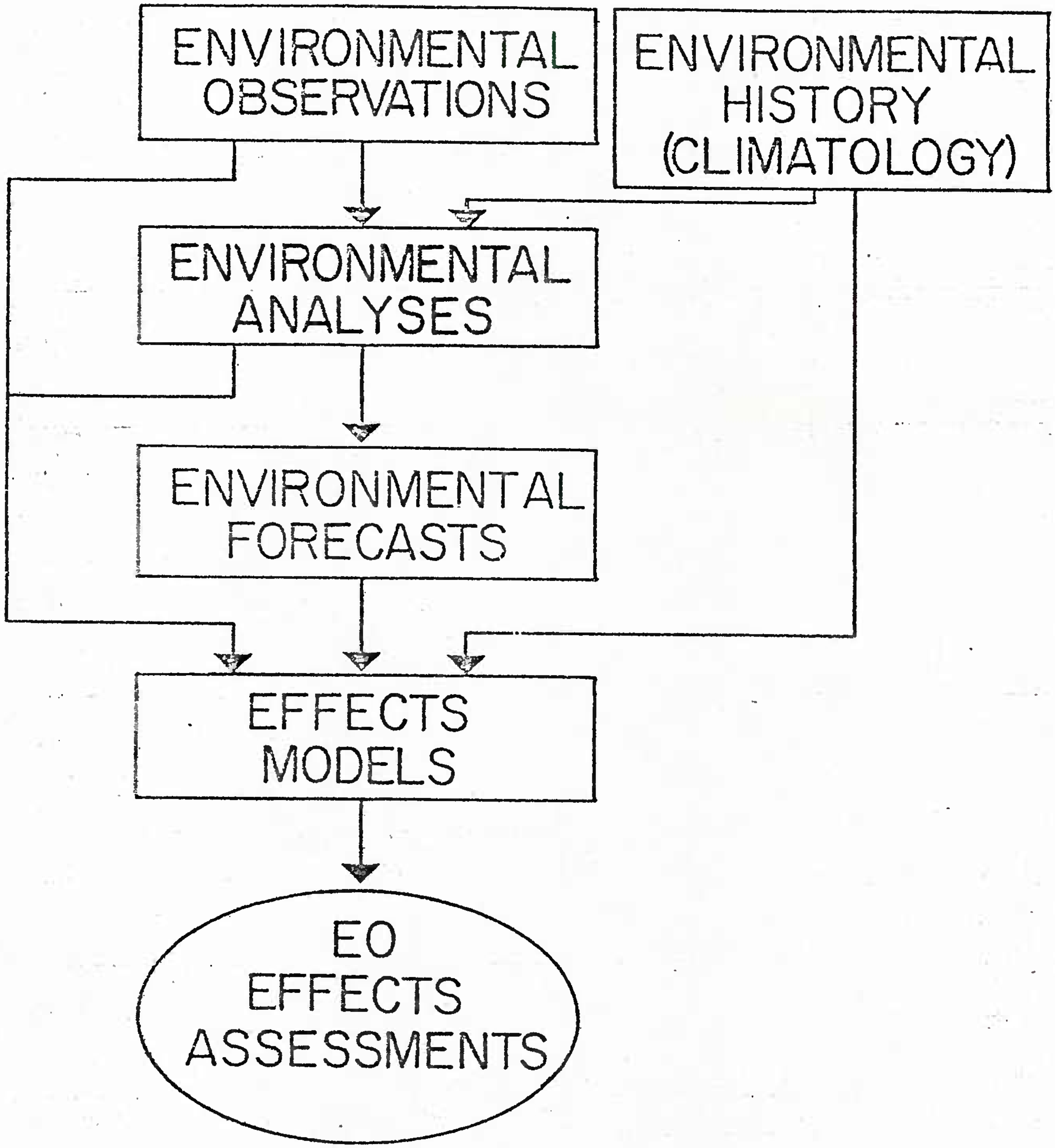

Figure I. Environmental support process for EO Systems.

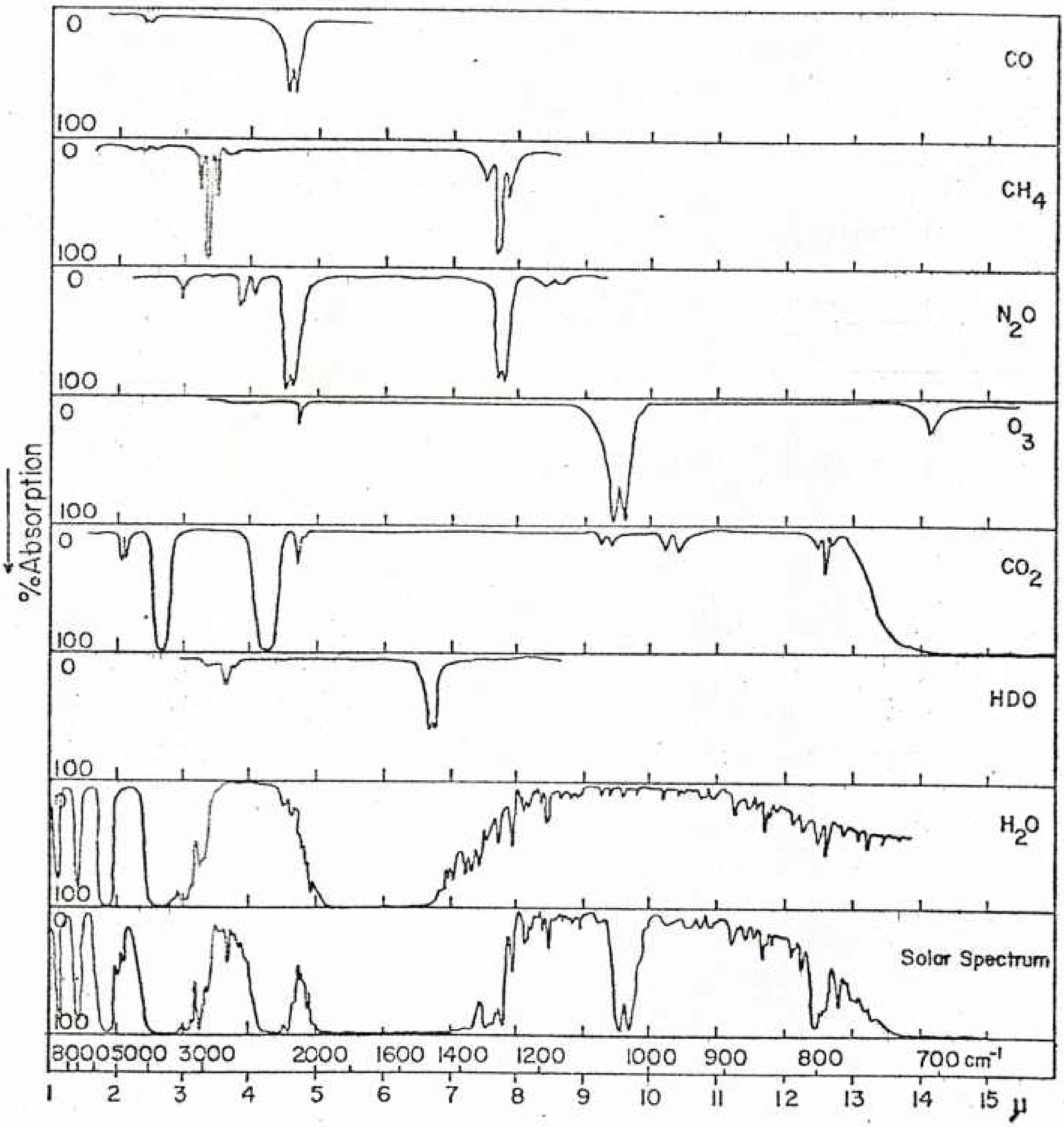

FIGURE 2 The Near-Infrared Solar Spectrum (bottom curve). Other curves are laboratory spectra of the molecules indicated. [4]

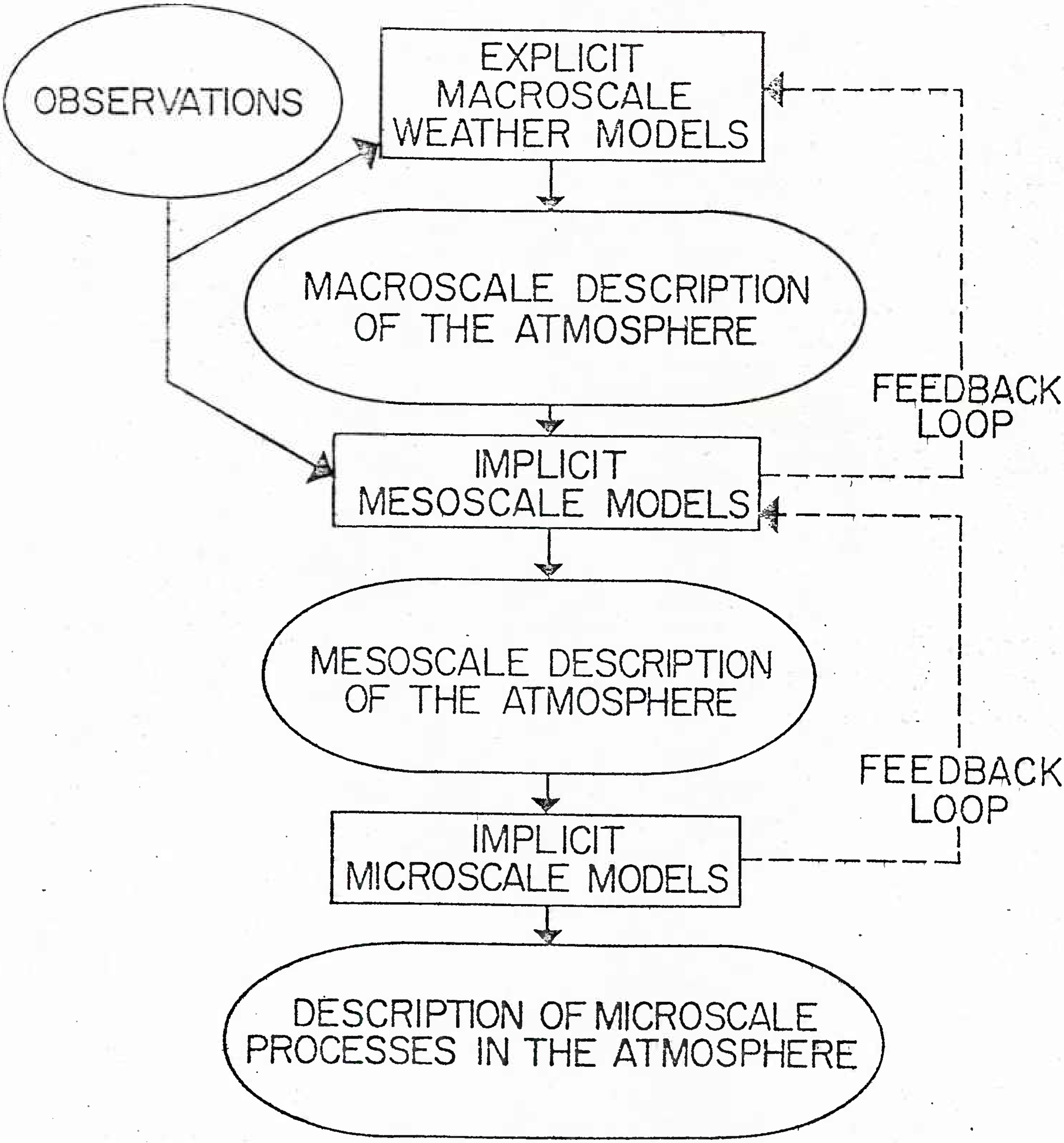

FIG. 3. Schematic of general strategy for specifying microsale processess.

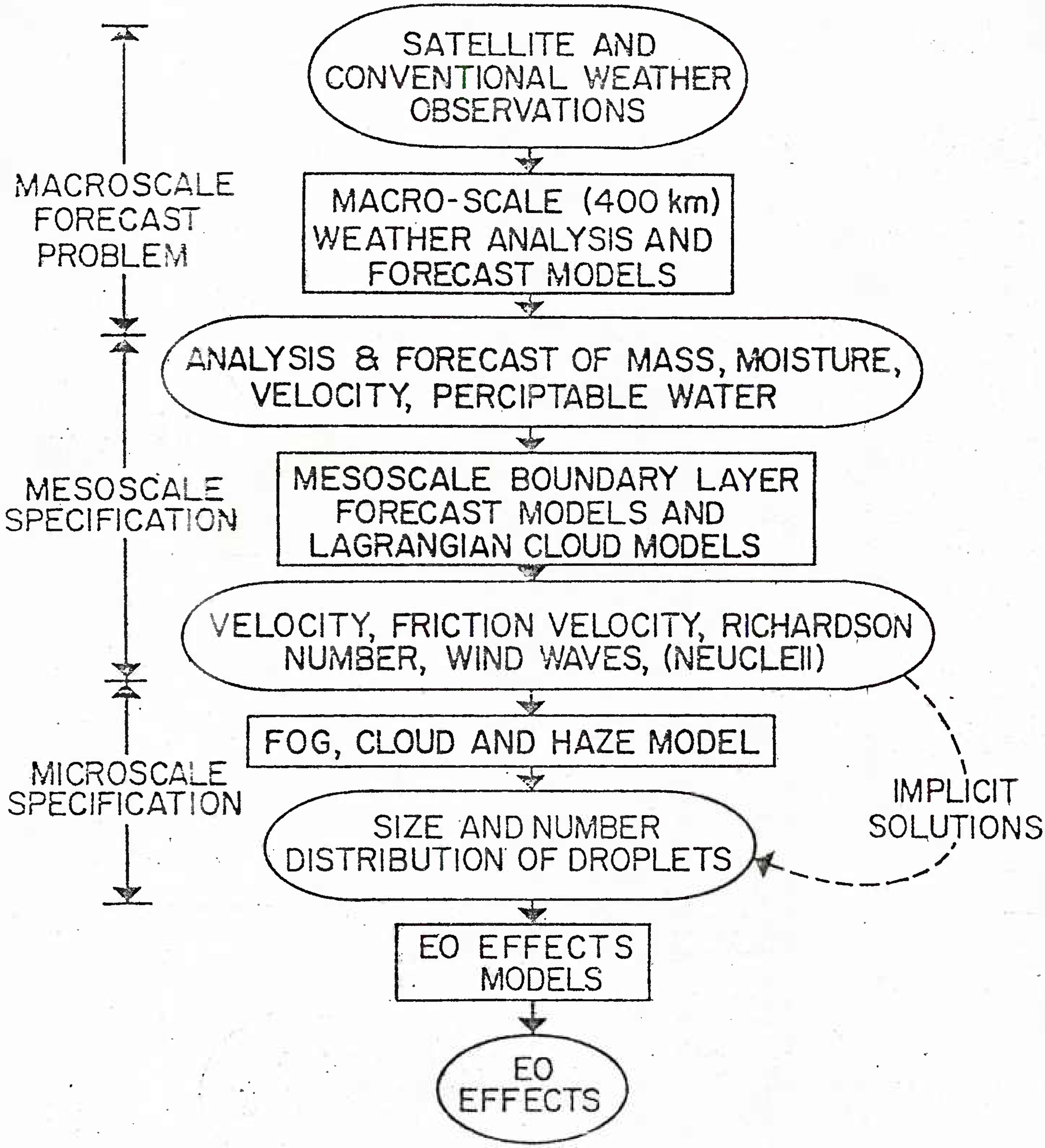

FIG. 4. The basic explicit hydrometeor forecast problem.

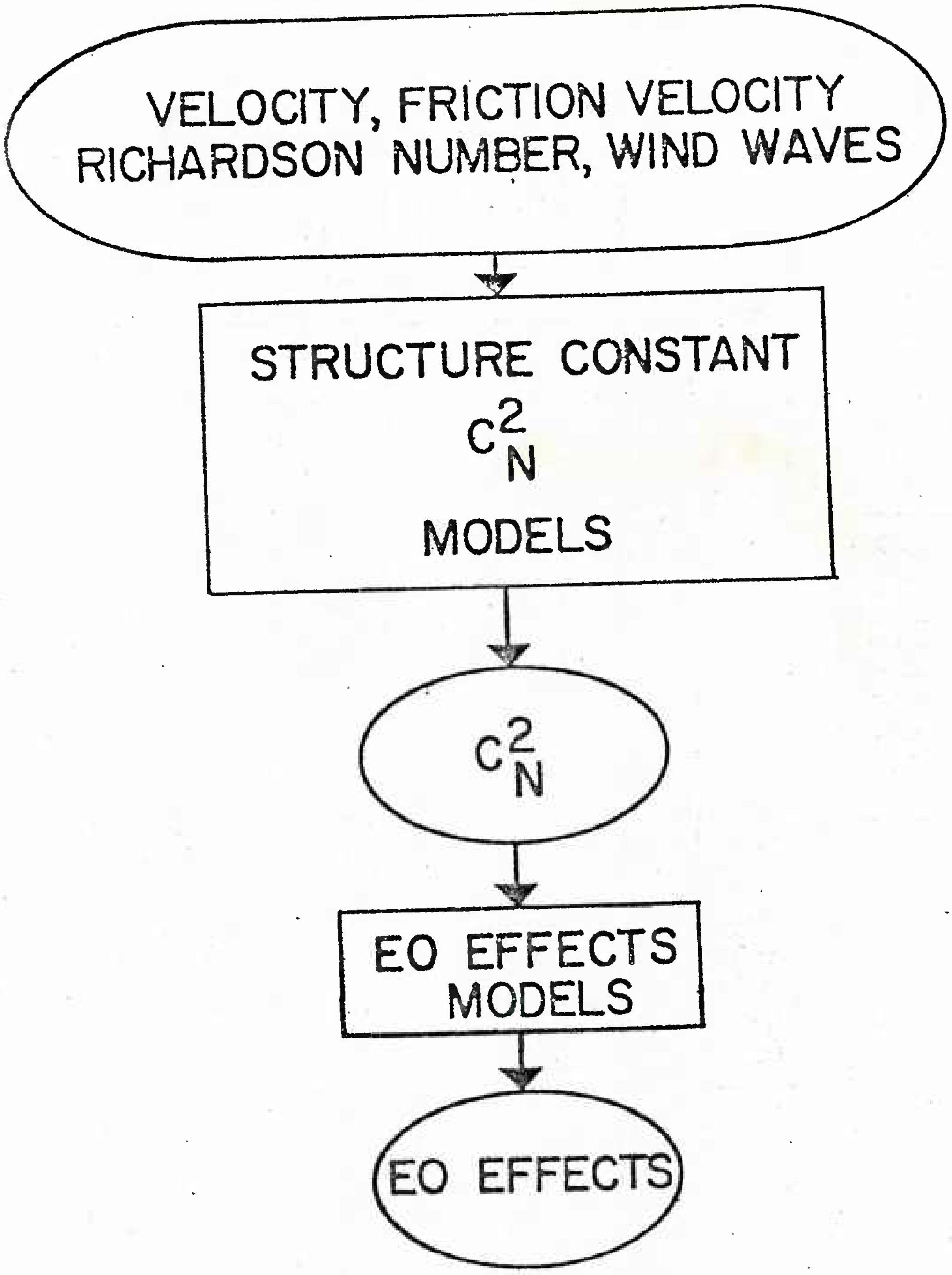

FIG. 5. The basic turbulence specification problem, starting with mesoscale specification.

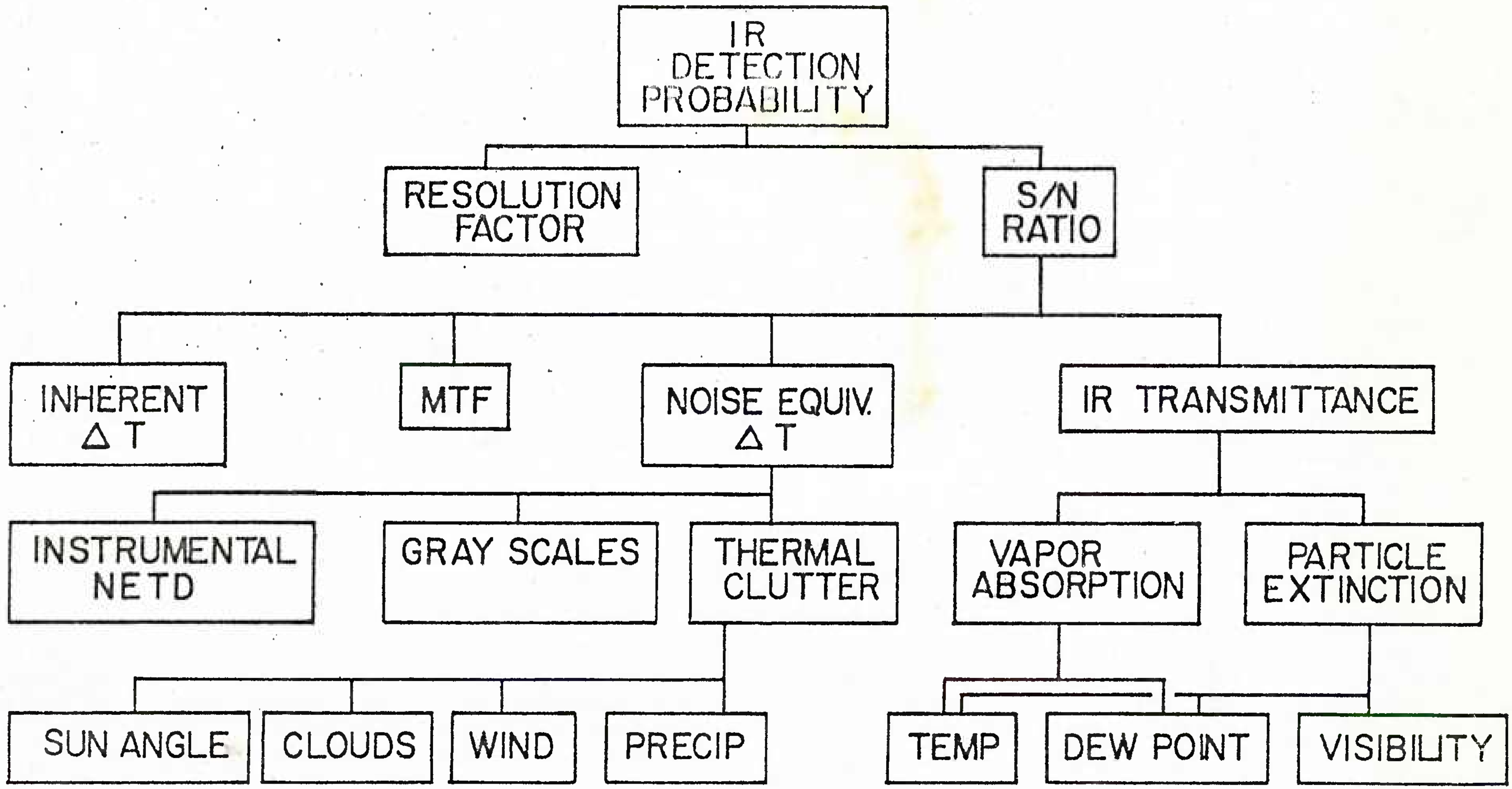

FIG. 6 IR detection probability functional relationships for FLIR.